CHAPTER 9: EFFICIENCY IN BOILERS

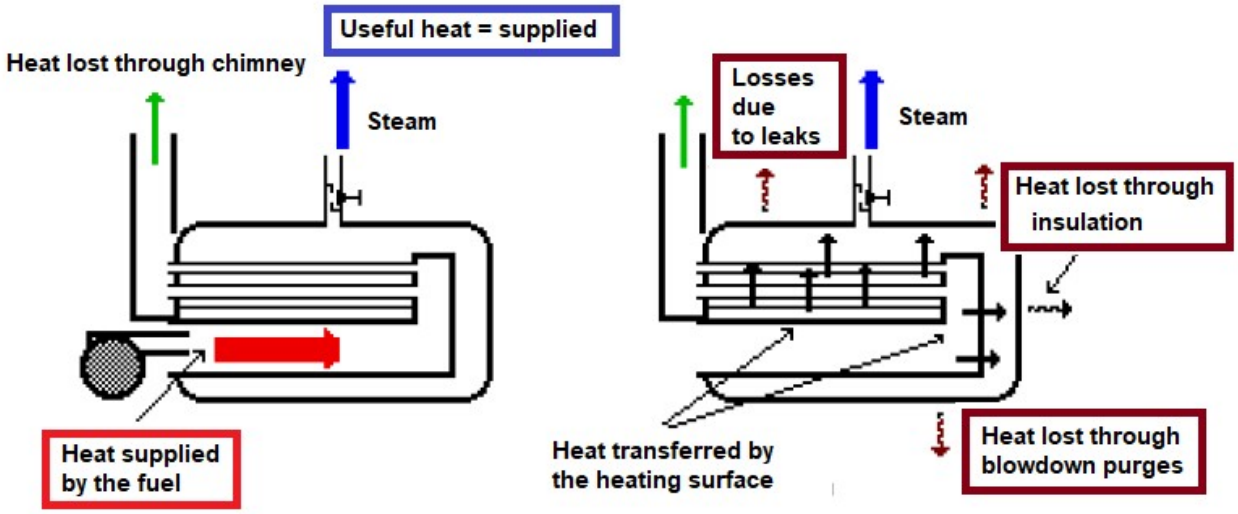
Measuring boiler efficiency means evaluating or measuring the percentage (%) of heat supplied by a fuel that is utilized.

This heat supplied by the fuel can be expressed as the Lower Heating Value (LHV) or the Higher Heating Value (HHV).

In boilers, we can broadly identify two types of heat loss:

One is caused by the **heat lost as hot gases exit through the chimney** (the air and fuel still present in these gases are considered to be at room temperature when used for combustion, although in some cases the fuel is heated by an external source such as electricity, but in practice, we will consider it as indicated at the beginning).

The second is the **heat loss caused by the boiler itself**, like any thermal equipment (heat losses through thermal insulation, water and steam losses, including necessary blowdowns, etc.).



Combustion efficiency:

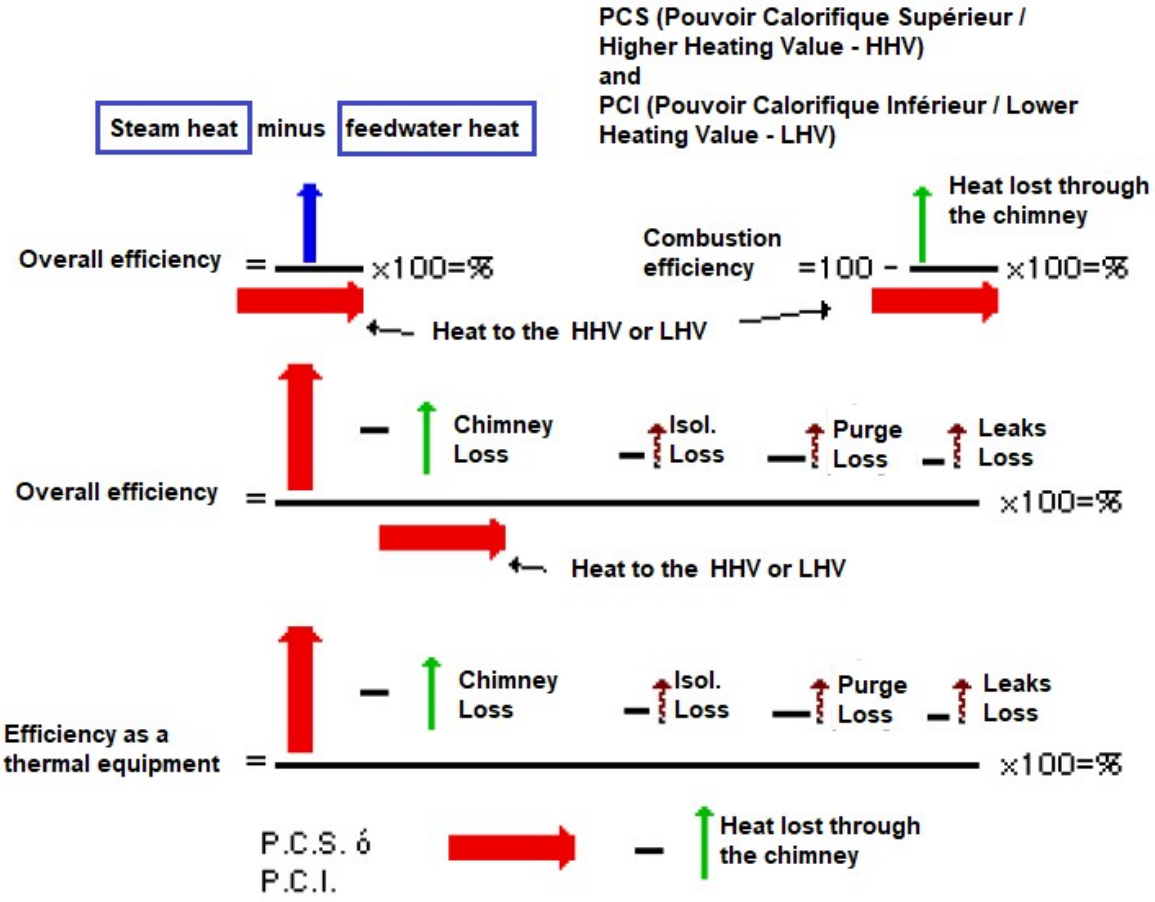
If we only consider the evaluation of the initial heat loss (through the flue gases), we can say that we are evaluating combustion efficiency: In this case, we are considering the heat that remained in the boiler, not the heat that is actually transferred to the steam.

By comparing measurements taken in the same boiler over a short period, we are actually comparing its combustion quality (excess air, unburned gases, etc.).

If we compare different boilers or the same boiler at different times, this combustion efficiency also takes into account the heat transfer conditions of the heating surface (soot buildup, scale on the water side, etc.) and direct losses to the outside (refractory lining, refractory casing, etc.).

It can also consider cases of internal ruptures in elements that direct hot gases to the heat exchange surfaces (baffles, diaphragms, vortices, etc.).

This is primarily noticeable by the increase in flue gas temperature. I believe this efficiency should be called **COMBUSTION AND HEAT TRANSFER EFFICIENCY.**



Boiler efficiency as a thermal equipment:

In this case, we are considering the percentage of heat supplied to the steam out of the total heat remaining in the boiler.

The heat remaining in the boiler is the percentage obtained from the calculation or measurement of combustion and transfer efficiency.

The heat supplied to the steam will be less due to heat losses through the boiler surfaces in contact with the boiler room air or through its structure. We must also add the losses caused by leaks of hot water and steam (taking into account necessary blowdown).

Boiler efficiency as a thermal equipment:

In this case, we are considering the percentage of heat supplied to the steam out of the total heat remaining in the boiler.

This efficiency, excluding steam and water losses (from blowdown), is fixed for a given pressure. Therefore, at higher vaporization rates, the percentage of heat transferred to the boiler will decrease.

For this reason, it is important that the boiler be designed for a normal operating rate of 70% to 80% of its capacity and that the water quality allows for minimal purge blowdown (maximum condensate recovery) and minimal steam losses with proper maintenance.

By considering combustion efficiency and the efficiency of the boiler as a thermal equipment, we can establish an overall efficiency.

The overall efficiency of a boiler is expressed as a percentage of the total heat supplied by the fuel (referred to the HHV or LHV) that is absorbed in the boiler and transferred by the steam.

To measure these efficiencies (combustion, boiler as a thermal equipment, or overall efficiency), we need to know or obtain a series of values that we will relate in mathematical expressions for each case.

These measurements will be taken with instruments (gas meters, thermometers, pressure gauges, flow meters, etc.) and values will be taken from tables (steam tables, Ostwald diagrams for gases, etc.).

Let's look at a practical way to perform these calculations, with an approximate value sufficient for normal evaluation work at low and medium pressure.

Boiler efficiency is established by two methods: Direct and Indirect.

Direct Efficiency (approximate):

Measure the amount of steam in kg/h (or the amount of feedwater less blowdown and losses in kg/h), its pressure, and its temperature, including the feedwater temperature.

At the same time, measure the amount of fuel consumed to produce this steam. From saturated steam tables, obtain the total heat of the steam (if unsaturated, use a superheated steam table) and the heat of the water at the feedwater temperature.

Using the following formula, you will obtain the approximate total efficiency directly:

$$\textit{Total Efficiency \%} = \frac{\textit{Kgs.steam/h x (Kcal/Kg. steam - Kcal/Kg. water) x 100}}{\textit{Kgs. fuel/h x Calorific power Kcal./Kg.}}$$

Indirect Efficiency (approximate):

In this case, chimney losses are measured, and by calculating their percentage, we can establish that:

100 - % losses in the flue gases = % Combustion efficiency (and transfer)

The losses from the boiler itself (blowdown, heat loss through its body to the room, water and steam losses) are not taken into account (since these are related to the Total Efficiency and not to the Combustion and Transfer Efficiency).

To calculate these chimney losses, we need to know:

Ai = Minimum theoretical air required by the fuel (kg/kg),

Ag = Water formed by the fuel + water from the fuel's moisture content (kg).

A% = Excess air (measured by CO2 or O2),
equal to (Excess air coefficient) x 100 - 100 = A% (see graphs in this chapter).

Cp = Specific heat of the combustion gases (approximately 0.25 kcal/kg).

This specific heat varies according to the composition of the gases and the operating temperature range (generally no less than 0.25 kcal/kg and no more than 0.26 kcal/kg).

T2 = Flue gas temperature in °C

T1 = Combustion air temperature in °C (room air temperature)

Heat value (HVL and LHV) of the fuel (kcal/kg)

$$\textit{Combustion efficiency HVL} = 100 - \frac{[(1+Ai \times (1+A\%/100) \times Cp \times (T2-T1) + Ag \times 600] \times 100}{HVL}$$

$$\textit{Comb.P.C.I. efficiency} = 100 - \frac{[(1+Ai \times (1+A\%/100)) \times Cp \times (T2-T1)] \times 100}{P.C.I.}$$

Note that in the combustion efficiency calculation related to the hottest part of the fuel, we have taken into account the heat absorbed by the water contained in the fuel as it evaporates (Ag x 600).

We have not taken into account the superheating of the water, the humidity of the air, or the unburned gases (since we are making a practical, approximate calculation).

Let's look at the minimum theoretical air quantity required, Ai, for common fuels:

Heavy Fuel Oil.....13.22 kg of air per kg of fuel oil

Super Gas.....15.7 kg of air per kg of super gas
Natural Gas.....16.3 kg of air per kg of natural gas

Firewood consumption varies with moisture content
(since higher moisture content means less fuel):

Firewood with 25% moisture.....4.8 kg of air per kg of firewood
Firewood with 30% moisture.....4.48 kg of air per kg of firewood
Firewood with 35% moisture.....4.16 kg of air per kg of firewood
Firewood with 0% moisture.....6.4 kg of air per kg of firewood

Rice husks with 10% moisture content.....4.36 kg of air per kg of husk.
Rice husks with 0% moisture content.....4.85 kg of air per kg of husk.

For the calculation of Ag x 600 we can substitute it with = P.C.S.- P.C.I. since the difference between them is the amount of heat in evaporating the total water (assuming that the fuel does not bring extra water after the analysis of the Heat Pump).

If we consider the Total Efficiency (which is equal to the heat delivered to the steam relative to the heat delivered by the fuel), we must consider the efficiency of the boiler as a thermal equipment (taking into account losses due to insulation, steam, water, and blowdown).

Since the boiler receives the heat we calculated in the Combustion and Transfer Efficiency (heat from the fuel - heat lost in the chimney) and delivers a smaller amount of heat to the steam due to these losses (insulation, blowdown, water and steam losses).

We can establish that:

Total Efficiency = Combustion Efficiency x Boiler Efficiency (as a Thermal Equipment).

With all efficiencies referring to the same calorific value (HHV or LHV), we can say that:

Total Direct Efficiency = Total Indirect Efficiency

Therefore, we can establish that the efficiency of the boiler as a thermal equipment is:

Boiler Efficiency (equipment) = Total Direct Efficiency ÷ Indirect Combustion Efficiency

The efficiency of a boiler as a thermal equipment, excluding blowdown and steam and water losses, is currently around 97% to 99% of the boiler's maximum output, thanks to the most compact and better-insulated modern boiler designs.

This means that the lower the boiler's steam output, the more significant this loss becomes. Therefore, boilers should be selected to operate at 70% of their steam production capacity, leaving 30% to handle momentary or transient loads.

Older boilers, with their extensive structure, refractory materials, and poor or inadequate insulation, had losses of around 10% to 15%.

This made them prime candidates for replacement with modern boilers (since these losses often represented the cost of a new boiler paid for in a single year).

Fuel Savings Calculation, Improving Combustion;

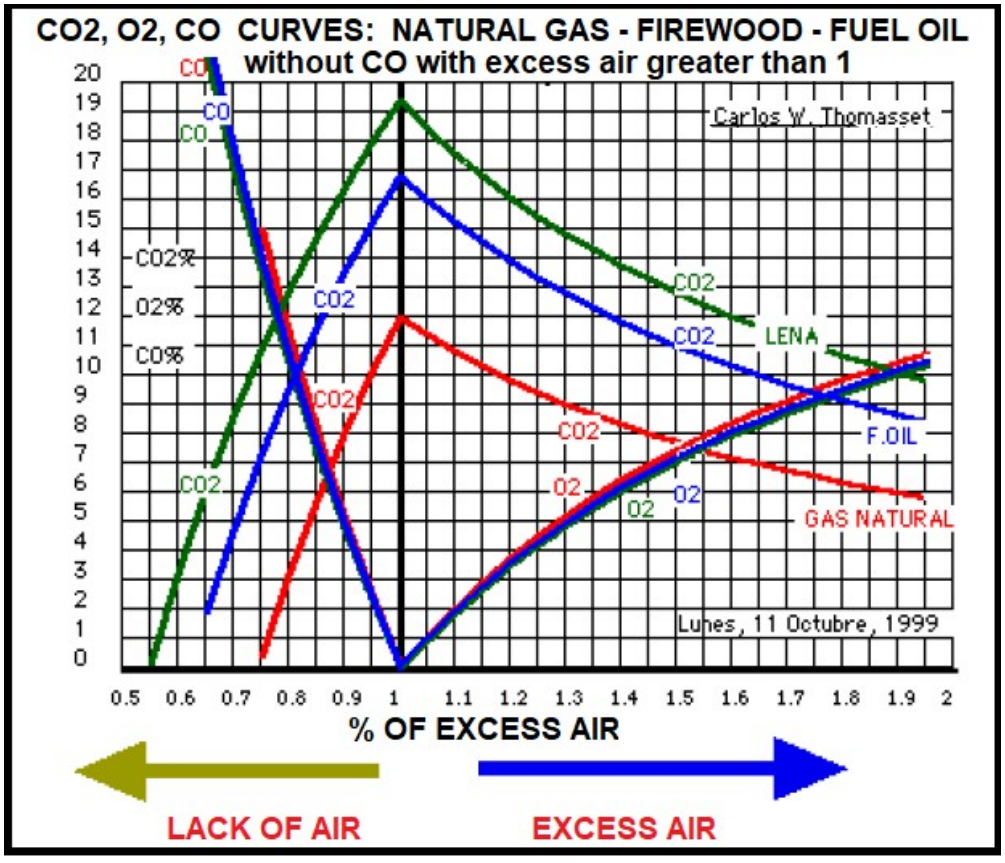
Assuming the boiler remains the same, its overall efficiency as a thermal equipment will remain unchanged. Fuel savings can be measured and calculated by measuring the combustion and heat transfer efficiency (by measuring excess air and using a thermometer):

$$\text{Savings \%} = \frac{[\text{Improved Combustion Efficiency \%} - \text{Previous Combustion Efficiency \%}] \times 100}{\text{Improved Combustion Efficiency \%}}$$

Fuel Savings Calculation, Reducing Blowdown and Leaks, and Improving Insulation:

$$\text{Savings \%} = \frac{[\text{Improved Total Efficiency \%} - \text{Previous Total Efficiency \%}] \times 100}{\text{Improved Total Efficiency \%}}$$

We have not taken into account unburned fuel in the form of ash, soot, etc.
Measuring Excess Air in Flue Gases:
To measure excess air in flue gases, we must use instruments and charts.
Not all excess air is due to air entering through the burner; there may be leaks through the boiler casing or inspection hatches. This air should be removed as much as possible by installing gaskets (or caulking cracks or openings that don't seal properly).

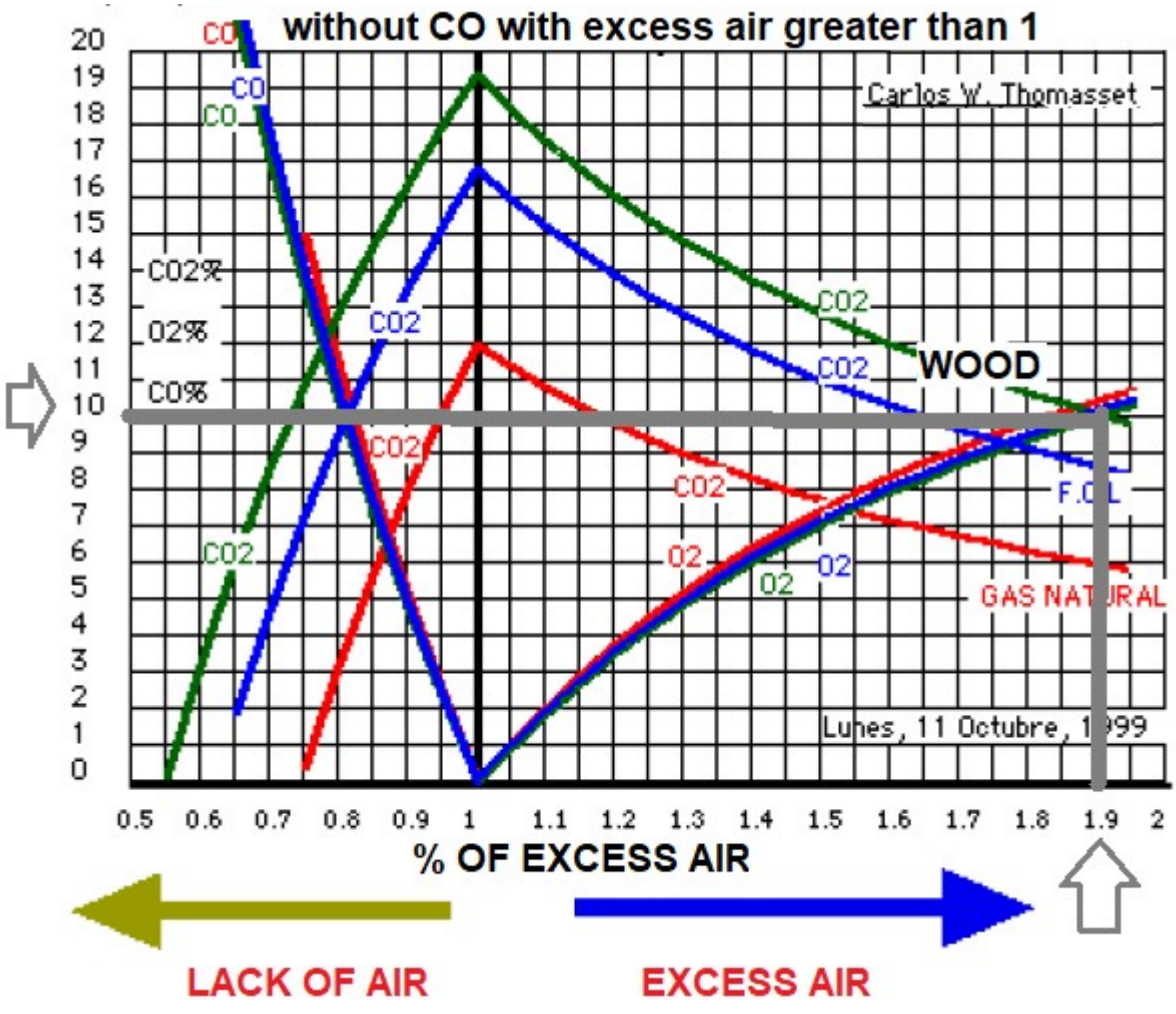


This graph provides an idea of the excess air coefficient when measuring chimney gases.

It has the drawback that it assumes there is no presence of CO (carbon monoxide, i.e., carbon that has "burned" with only one oxygen atom and released only 30% of its heat) when there is excess air.

Excess air begins at a value greater than 1, with the percentage excess being equal to the number minus 1 per 100.

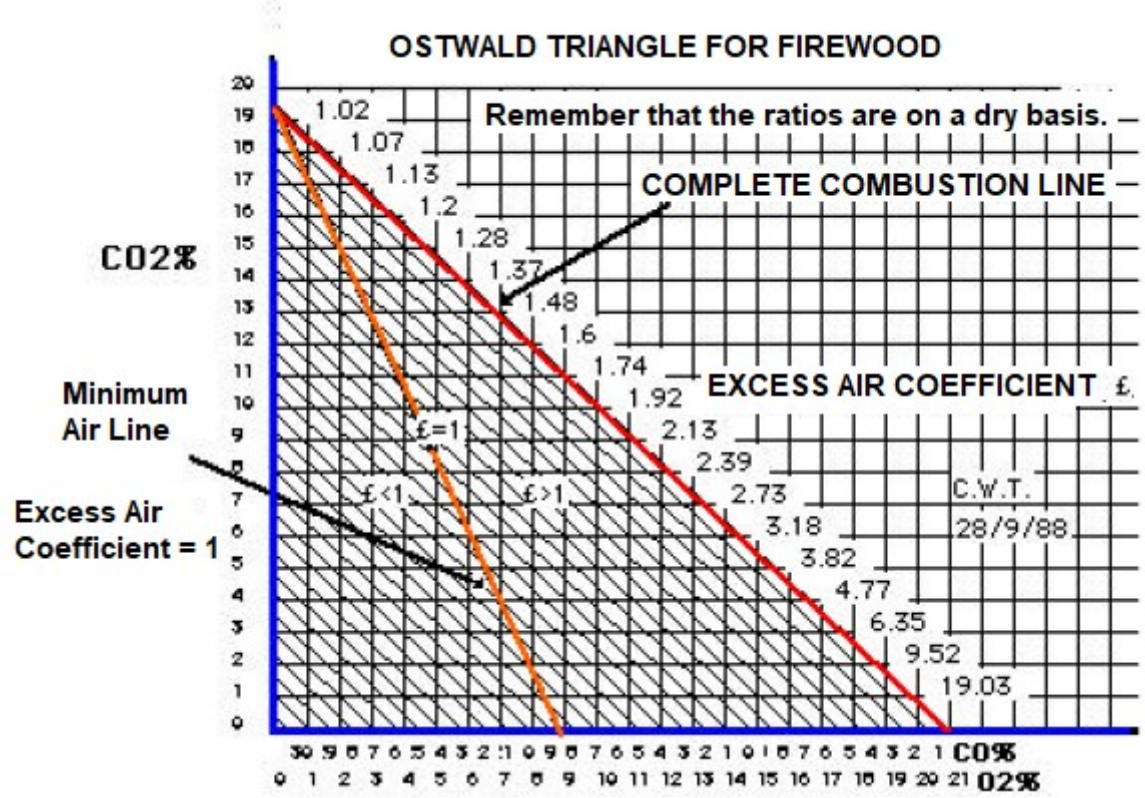
Example: measuring firewood, we have a CO2 of 10%. On the vertical axis, we read 10% CO2 and follow the horizontal axis
until it intersects the CO2 curve corresponding to the firewood. From that point, we go down the vertical axis to the horizontal axis where we read the Excess Air Coefficient 1.9. The percentage of excess air will be: 1.9 - 1 = 0.9 per 100 = 90% Excess Air.



In other words, we have 90% excess air, but with firewood, we typically need an excess of 40-50% air. Therefore, the actual excess air will be 90% - 40% (or 50%) = 40% (or 50%). **We must try to adjust the amount of air needed to avoid this high excess.**

We see that by measuring O2 (oxygen), the excess air is practically the same for the three fuels mentioned above for the same oxygen reading. Therefore, it is preferable to measure oxygen if possible, as it allows us to measure the excess air without knowing the exact composition of the fuel.

Since CO commonly appears in wood and gas due to poor combustion, it is preferable to use the OSTWALD triangle, for which we must always measure the CO2% or the O2%, but always measure the CO (which, even if there is excess air, can be produced by poor combustion).



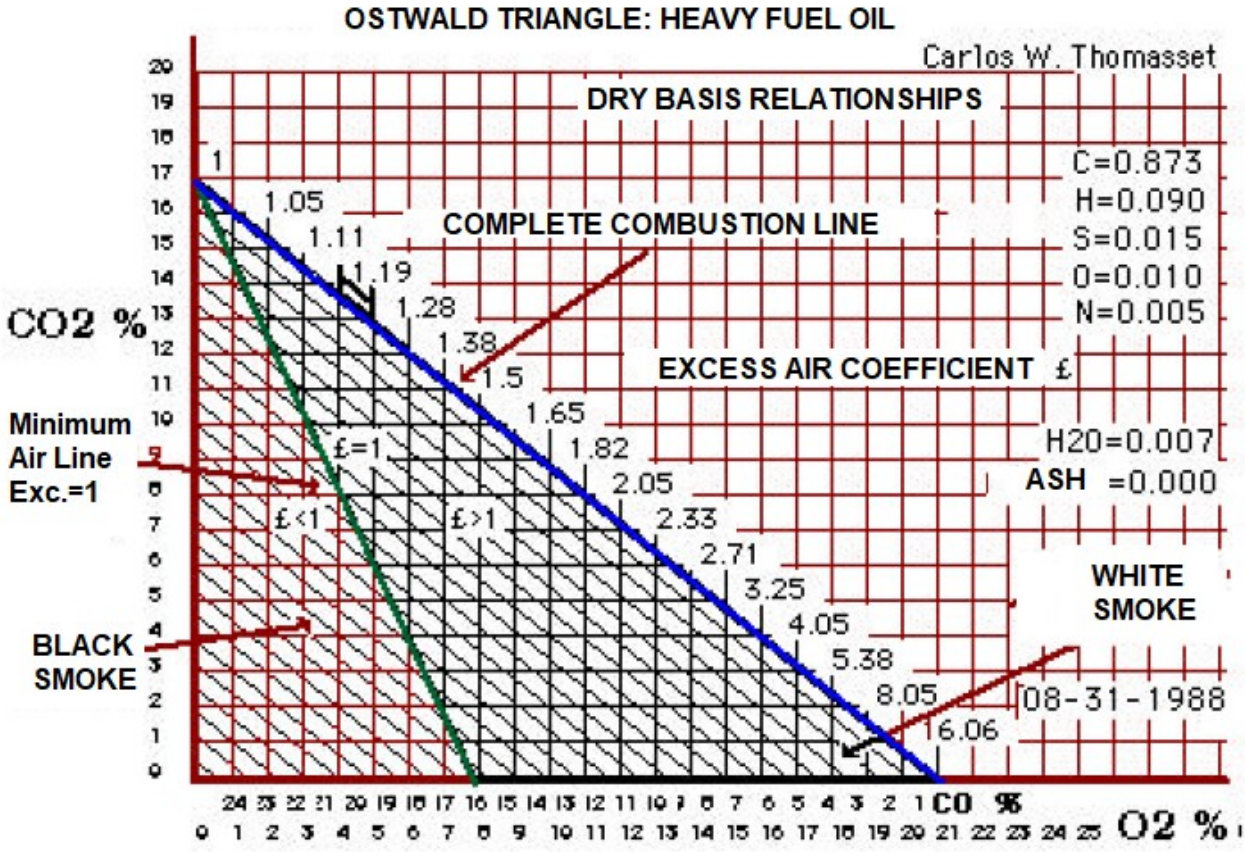
OSTWALD TRIANGLE FOR FIREWOOD

To use the Ostwald triangle for firewood, it is advisable to measure CO2 or O2 and CO in both cases (or all three is better: with an ORSAT, see Chapter 5 Part 7, 4 or 4a of 5).

The vertical line connects to the CO2 % readings, and the horizontal line connects to the O2 % readings in the lower numbering. If there is no CO, plotting the CO2 and O2 values will cause them to intersect at the hypotenuse, where the Excess Air Coefficient is read.

If we measure the CO% (which is advisable), we must read its value on the horizontal line corresponding to CO% and follow the lines parallel to the hypotenuse inside the triangle until they intersect at the point where they should join the lines for CO2% and O2%.

In this case, the Excess Air Coefficient must be obtained by drawing a line parallel to the line that marks the Excess Air Coefficient equal to 1 (minimum air required). This line would pass through the point of intersection of the lines (for CO2, O2, and CO) and would intersect the hypotenuse where the value of the Excess Air Coefficient would be read. (These lines were not drawn in this drawing to avoid obscuring the diagram).



OSTWALD TRIANGLE FOR HEAVY FUEL OIL

In plotting the Ostwald triangle, we assumed that CO is present only as unburned gas. However, in practice, when considering the presence of other unburned elements, such as hydrogen, we can estimate that we have the same amount of these unburned gases as the amount of CO.

In practice, normally if we measure with an ORSAT (CO2, CO and O2) it is very difficult for them to join at a point (100% theoretical point), so we have to

draw the triangle of the cuts between each of the lines (CO2 and CO, CO2 and O2, CO and O2) and take the midpoint equidistant from the 3 sides of this small triangle.

There may be significant differences between the ORSAT measurement and the Ostwald triangle we have, since the plot depends on the composition of the wood, its combustion, and measurement errors; however, its approximation is very useful for understanding combustion problems.

Calorific Values of Common Fuels:

HV (Higher Heating Value) LHV (Lower Heating Value)

The difference lies in the fact that the LHV subtracts the heat required to vaporize the water formed during hydrogen combustion and the water present as moisture in the fuel itself (LHV = HV - 600 x Total Water), while the HVV assumes the water is condensed (at 0°C), measuring all available heat.

Heavy Fuel Oil (Nº6)
P.C.S. =10300 Kcal./Kg. - P.C.I. = 9700 Kcal./Kg.
(HHV 18527 BTU/lb - 17448 LHV BTU/lb)

Super gas (bottles)
P.C.S. =12800 Kcal./Kg. - P.C.I. =11800 Kcal./Kg.
(HHV 23024 BTU/lb - 21225 LHV BTU/lb)

Natural gas
P.C.S. = 12290 Kcal/Kg. - P.C.I. = 11100 Kcal/Kg.
(HHV 22107 BTU/lb - 19966 LHV BTU/lb)

This value for natural gas corresponds to the Paysandú branch line (Uruguay, June 2000); the values should be taken from the information of the corresponding branch line (according to origin).

The volume of natural gas is generally expressed in cubic meters (m^3) at a temperature of 15°C and 1 atmosphere of pressure. Its specific gravity relative to air (approximately 0.62) or its weight per cubic meter (density) at a temperature of 15°C and 1 atmosphere of pressure (approximately 0.76 kg/m^3) allows us to establish a globular heat capacity (GHC) of 9,400 $kcal/m^3$ and a lower heating value (LHV) of 8,490 $kcal/m^3$ under the aforementioned pressure and temperature conditions.

These values vary according to the gas extraction zone and the gas treatment process.

Since firewood has different moisture levels, its calorific value will depend on the percentage of moisture in it, not only because of the water it forms and contains, but also because of the percentage of matter that is occupied by water (if the moisture is 40%, the dry matter will be 60% - with its water of formation - this water and 40% will be the water to evaporate).

Eucalyptus firewood:

Eucalyptus firewood, 0% moisture (completely dry)
P.C.S. = 4685 Kcal/Kg. P.C.I.= 4300 Kcal/Kg.
(HHV 8427 BTU/lb - 7735 LHV BTU/lb)

Eucalyptus firewood, 25% moisture
P.C.S. = 3510 Kcal/Kg. P.C.I.= 3080 Kcal/Kg.
(HHV 6314 BTU/lb - 5540 LHV BTU/lb)

Eucalyptus firewood, 30% moisture
P.C.S. = 3280 Kcal/Kg. P.C.I.= 2830 Kcal/Kg.
(HHV 5900 BTU/lb - 5090 LHV BTU/lb)

Eucalyptus firewood, 35% moisture
P.C.S. = 3045 Kcal/Kg. P.C.I.= 2590 Kcal/Kg.
(HHV 5477 BTU/lb - 4658 LHV BTU/lb)

Eucalyptus firewood, 41% moisture
P.C.S. = 2760 Kcal/Kg. P.C.I.= 2290 Kcal/Kg.
(HHV 4964 BTU/lb - 4119 LHV BTU/lb)

Rice Husk 10% moisture
P.C.S. = 3100 Kcal/Kg. P.C.I.= 2800 Kcal/Kg.
(HHV 5576 BTU/lb - 5036 LHV BTU/lb)

When firewood is cut in eucalyptus forests, its moisture content exceeds 60%.

The moisture content is given on a wet basis (% H w.b.).

That is, a quantity of **firewood is weighed ("Ph" Wet Weight), dried in a kiln at a low temperature (approximately 105°C, 221°F)** until it reaches a constant weight, and **then weighed again ("Ps" Dry Weight).**

The moisture percentage is calculated as follows:

% H b.w. = [(Ph - Ps) ÷ Ph] x 100

Be careful with the moisture content given on a dry basis (% H b.w.) (used by loggers, those who harvest and sell firewood), which is equal to:

% H b.w. = [(Ph - Ps) ÷ Ps] x 100

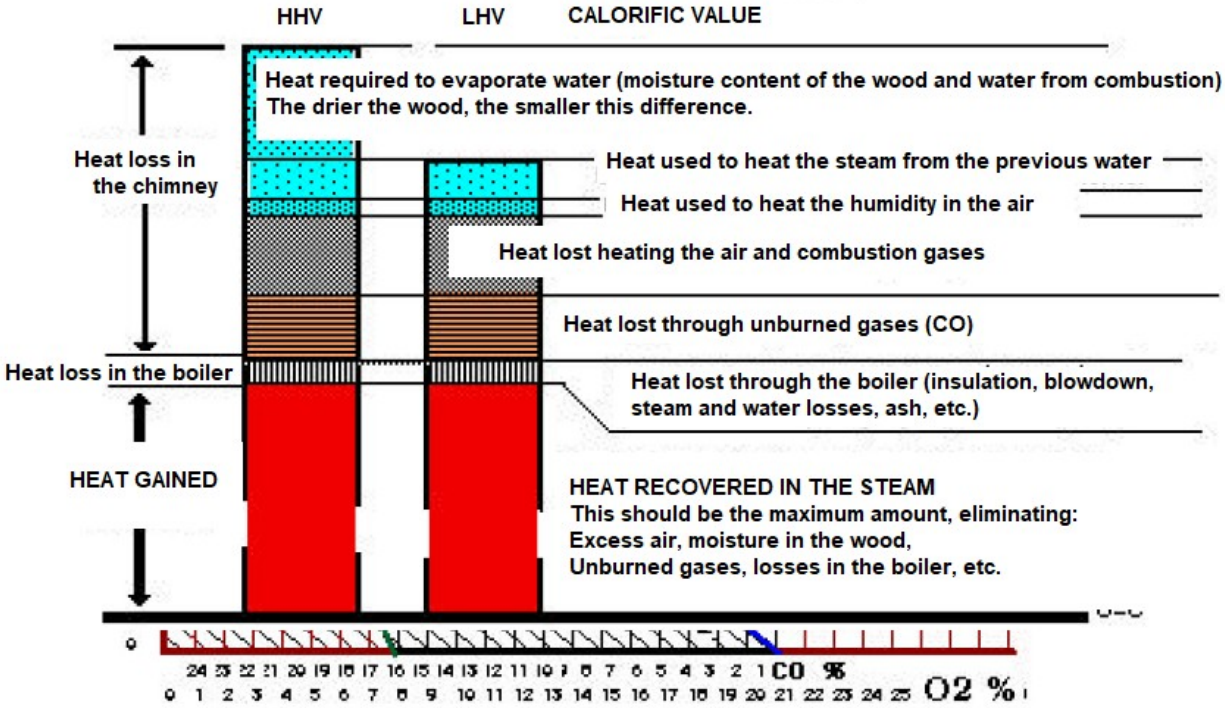
If we are given the moisture content on a dry basis (% H b.w.), we can convert from dry basis to wet basis:

% H b.w. = [% H b.w. ÷ (% H b.w. + 100)] x 100

Example: Firewood with a dry basis moisture content of % H b.d. = 25%. Applying the above, % H b.h. = 25 / (25 + 100) x 100 = 20% H b.h.

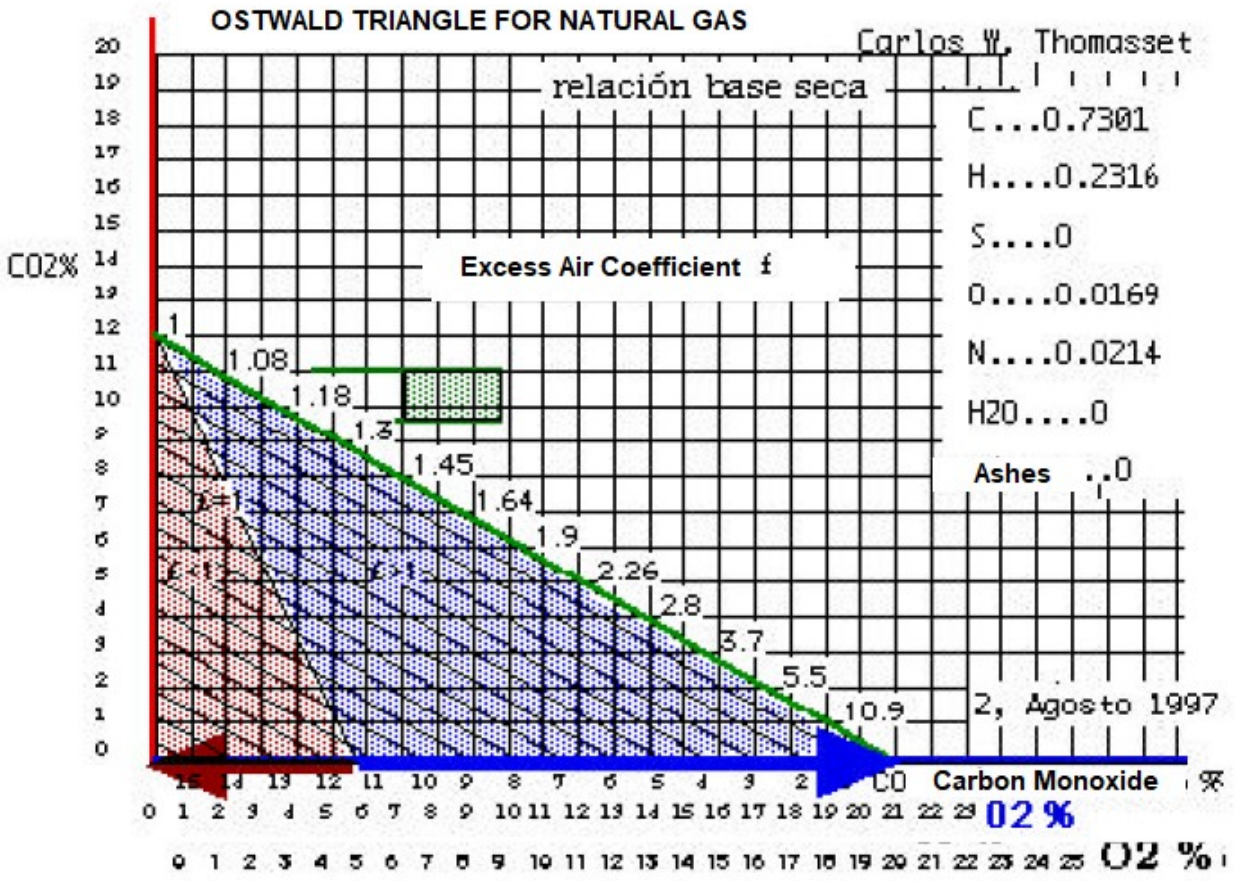
The two moisture values mean the same thing, but are expressed in different quantities. Therefore, it is necessary to clarify which basis (wet or dry) they refer to.

Comparative table when considering calorific values: higher and lower.


HHV
LHV
CALORIFIC VALUE
Heat required to evaporate water (moisture content of the wood and water from combustion)
The drier the wood, the smaller this difference.
Heat loss in the chimney
Heat used to heat the steam from the previous water
Heat used to heat the humidity in the air
Heat lost heating the air and combustion gases
Heat lost through unburned gases (CO)
Heat loss in the boiler
Heat lost through the boiler (insulation, blowdown, steam and water losses, ash, etc.)
HEAT GAINED
HEAT RECOVERED IN THE STEAM
This should be the maximum amount, eliminating:
Excess air, moisture in the wood,
Unburned gases, losses in the boiler, etc.
CO %
O2 %

Note that the absolute amount of heat utilized in the steam is the same in both cases; the percentage varies because the lower heating value (LHV) does not account for the heat of vaporization of the water (from humidity and combustion).

Apparently, the efficiency percentage at LHV is higher than that given with LHV, but when referred to the absolute heat utilized in the steam, it is the same. We see this in the case of wood.



Ostwald Triangle for Natural Gas

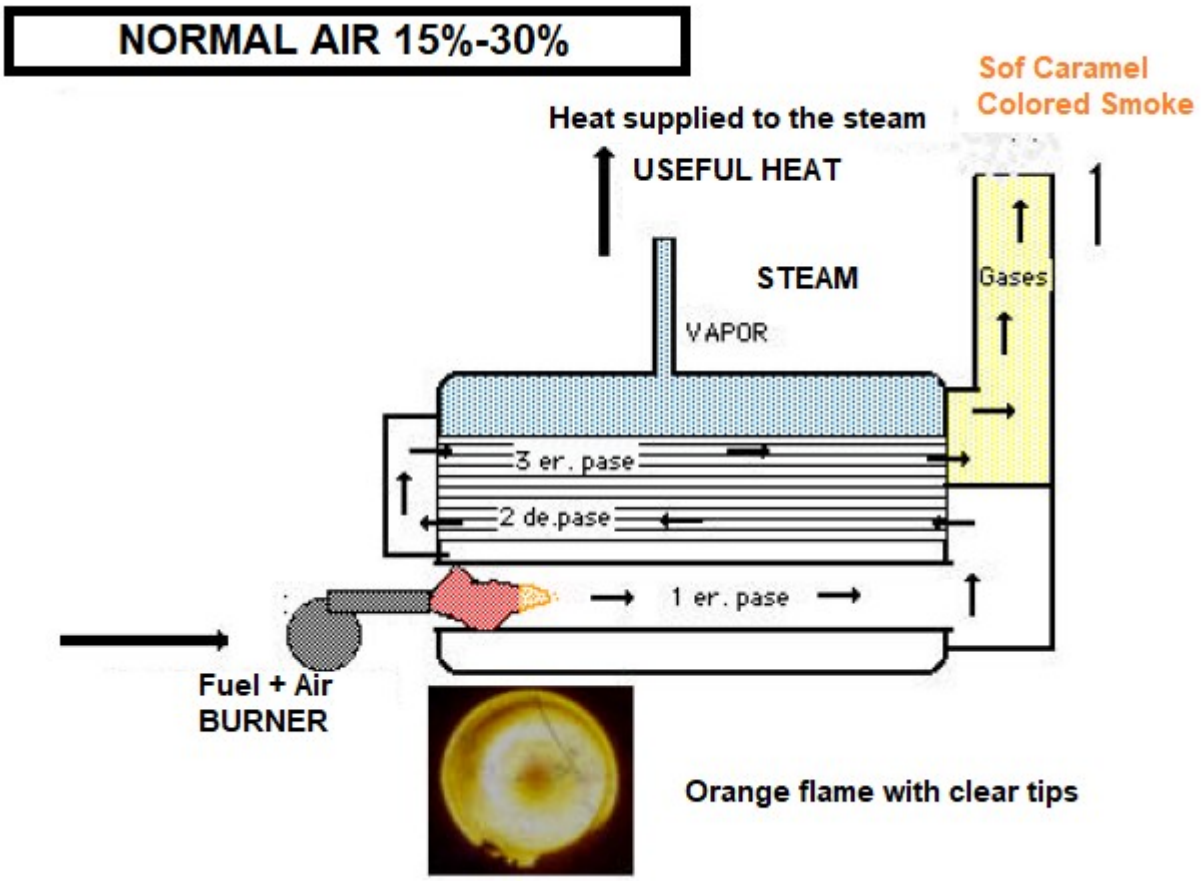
In summary: To improve each of the efficiencies studied, the following should be done:

<u>To improve combustion efficiency:</u>

Minimize the excess air required for combustion and air infiltration through joints or leaks in the boiler structure. Reduce losses from unburned gases by improving combustion conditions (atomization, fuel and air temperature, fuel-air mixture, fuel moisture, combustion temperature or zone where combustion occurs, etc.), and clean heat transfer surfaces.

Soot and ash are excellent insulators; chimneys and combustion chambers must be cleaned regularly.
Keep the water and steam side surfaces free of scale and insulating sludge by applying the appropriate chemical treatment.

Maximize the combustion chamber's heat transfer surface by adjusting the flame to the correct position for complete combustion, etc.



To improve the efficiency of the boiler as a thermal equipment:

in this case, we must find ways to prevent heat loss from the boiler to the boiler room through its insulation and structure, and prevent water or steam leaks (from valve stems, caps, pump packing, etc.).

We should also seek the best quality water to avoid high percentages of purge (blowdown), return as much condensate as possible, and perform proper internal chemical treatment. Alternatively, we should maximize continuous purge (blowdown) with heat recovery using heat exchangers.

Any of the above improvements will contribute to an improvement in overall efficiency.

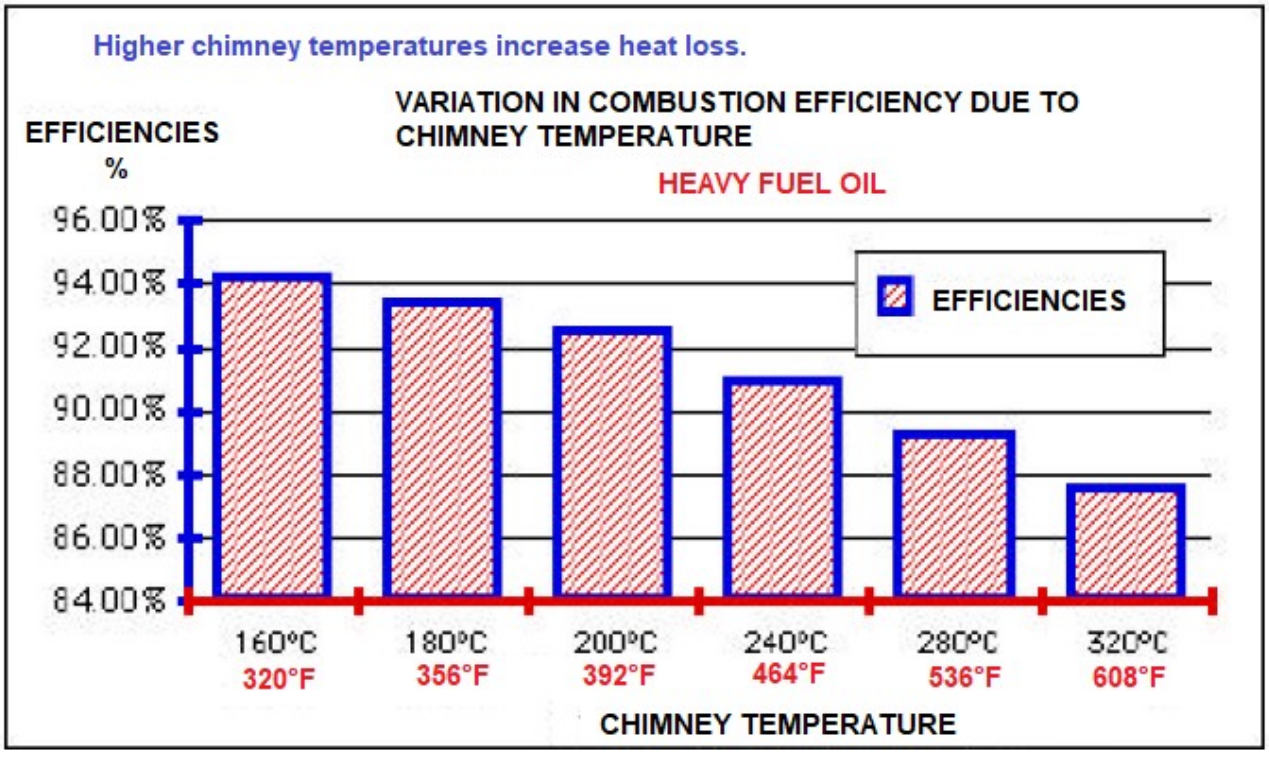
Remember to refer to efficiencies for the same calorific value (HHV or LHV), since although the quantities expressed as percentages are numerically different, their meaning when referring to each calorific value is not, thus preventing confusion in their numerical interpretation.

When expressing efficiencies, it is advisable to refer to the lower heating value (LHV). This allows us to more accurately judge the boiler's efficiency, as it largely eliminates the influence of fuel conditions (i.e., the hydrogen content that will form water and the moisture content).

In this way, we can compare boilers based on their individual efficiency, largely disregarding fuel quality.

When we express efficiencies in terms of the PCS (Percentage of Heat Used), we are taking into account fuel quality.

Therefore, when comparing boilers with PCS-measured efficiencies, we are actually comparing fuel quality rather than boiler quality, since the percentage differences are more noticeable due to the fuel than the boiler itself.



QUICK CALCULATION TABLES FOR COMBUSTION AND HEAT TRANSFER EFFICIENCIES (Calculated by the author)

The tables on the following pages allow you to calculate the COMBUSTION AND HEAT TRANSFER EFFICIENCY (LHV) from the CO2 or O2 measurement (if using the auxiliary ruler).

Remember that in this case, the tables correspond to CO2 measurements free of carbon monoxide (CO) or other unburned gases, i.e., complete combustion.

Since CO2 is generally the easiest to measure with a FYRITE or ORSAT, and the chimney temperature with a dial or electronic thermometer up to 500ºC (932°F) (placed in the chimney) and the ambient temperature with a common room thermometer.

The following tables are calculated for average fuels and in the case of firewood, the same with a wet basis moisture content of 25% (from 6 months to one year of seasoning, depending on the time of year, other values must be calculated).

Measure the CO2 content of the flue gases, the flue gas temperature, and the ambient temperature. Subtract the ambient temperature from the flue gas temperature (this will give the temperature difference, or the heat lost due to flue gas heating).

In the table provided (the right one of several shown in this chapter), enter the CO2 value on the left and the temperature difference at the top.

The intersection of the CO2 reading on the horizontal axis with the temperature reading on the vertical axis will give the COMBUSTION AND HEAT TRANSFER EFFICIENCY REFERRED TO THE LHV (Lower Heating Value).

To determine the excess air, refer to the CO2 or O2 curves, or the Ostwald triangles for each fuel, which are found in the book or in the auxiliary tables (following those related to the calculation).

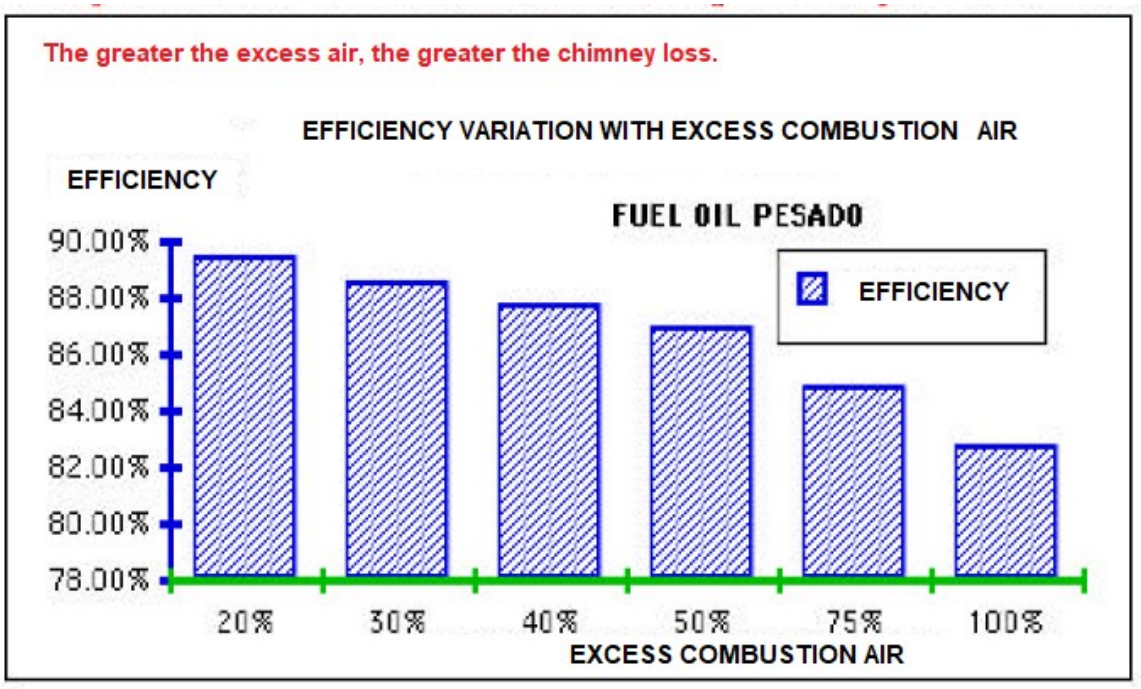
Printed on A4 hard paper/cardboard, the tables can be cut out (with scissors) to make up the EFFICIENCY RULES.

Using the corresponding tables for each fuel, cut out the appropriate space (indicated by dots) in the auxiliary tables.

You can then "fit" the corresponding table (for the same fuel) into the space below.

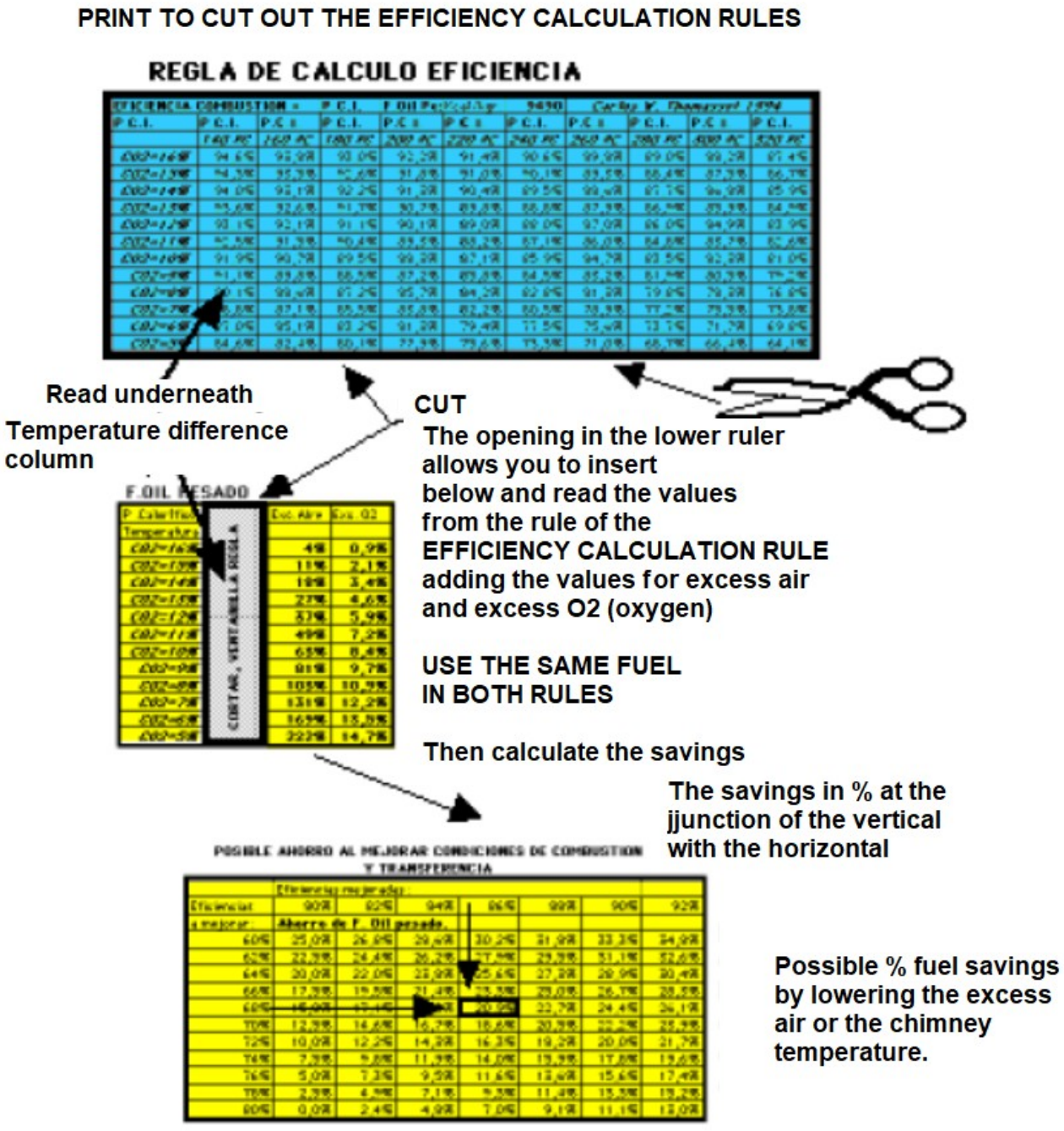
This will allow you to calculate the Combustion and Transfer Efficiency, as well as the excess air corresponding to each CO2 reading and the excess O2 (oxygen).

Alternatively, if you have an O2 meter instead of a CO2 meter, you can access each table.



Stoker Boiler Handbook 2011, C.W.T. – CHAPTER 9: Efficiency in Boilers

PRINT TO CUT OUT THE EFFICIENCY CALCULATION RULES
Read underneath
Temperature difference column
CUT the opening in the lower ruler allows you to insert below and read the values from the rule of the EFFICIENCY CALCULATION RULE
adding the values for excess air and excess O2 (oxygen)
USE THE SAME FUEL IN BOTH RULES
Then calculate the savings
The savings in % at the junction of the vertical with the horizontal
Possible % fuel savings by lowering the excess air or the chimney temperature.


PRINT TO CUT OUT THE EFFICIENCY CALCULATION RULES
REGLA DE CALCULO EFICIENCIA
Read underneath
Temperature difference column
CUT
The opening in the lower ruler allows you to insert below and read the values from the rule of the EFFICIENCY CALCULATION RULE adding the values for excess air and excess O2 (oxygen)
USE THE SAME FUEL IN BOTH RULES
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The savings in % at the jjunction of the vertical with the horizontal
POSIBLE AHORRO AL MEJORAR CONDICIONES DE COMBUSTION Y TRANSFERENCIA
Possible % fuel savings by lowering the excess air or the chimney temperature.

Pequeño Manual del Foguista 10a. ed. año 2011

GAS NATURAL P.C.I.

EFICIENCIA COMBUSTION =	P.C.I.	P.C.I.	P.C.I.	GasNatu Kcal/kgr.	11500	Carlos W. Thomasset 1998					
P.C.I.	P.C.I.	P.C.I.	P.C.I.	P.C.I.	P.C.I.	P.C.I.	P.C.I.	P.C.I.	P.C.I.	P.C.I.	P.C.I.
	140 ºC	160 ºC	180 ºC	200 ºC	220 ºC	240 ºC	260 ºC	280 ºC	300 ºC	320 ºC
CO2 =11,5%	94,3%	93,5%	92,6%	91,8%	90,9%	90,1%	89,2%	88,4%	87,5%	86,6%
CO2 =11,0%	94,1%	93,2%	92,4%	91,5%	90,6%	89,7%	88,9%	88,0%	87,1%	86,2%
CO2 =10,5%	93,9%	93,0%	92,1%	91,2%	90,3%	89,4%	88,4%	87,5%	86,6%	85,6%
CO2 =10,0%	93,6%	92,7%	91,8%	90,8%	89,9%	88,9%	88,0%	87,0%	86,0%	85,1%
CO2 =9,5%	93,4%	92,4%	91,4%	90,4%	89,4%	88,5%	87,5%	86,5%	85,5%	84,4%
CO2 =9,0%	93,1%	92,0%	91,0%	90,0%	89,0%	87,9%	86,9%	85,8%	84,8%	83,7%
CO2 =8,5%	92,7%	91,6%	90,6%	89,5%	88,4%	87,3%	86,3%	85,2%	84,1%	83,0%
CO2 =8,0%	92,3%	91,2%	90,1%	89,0%	87,8%	86,7%	85,5%	84,4%	83,2%	82,1%
CO2 =7,5%	91,9%	90,7%	89,5%	88,3%	87,1%	85,9%	84,7%	83,5%	82,3%	81,1%
CO2 =7,0%	91,4%	90,2%	88,9%	87,6%	86,4%	85,1%	83,8%	82,5%	81,2%	79,9%
CO2 =6,5%	90,8%	89,5%	88,2%	86,8%	85,5%	84,1%	82,7%	81,4%	80,0%	78,6%
CO2 =6,0%	90,2%	88,7%	87,3%	85,9%	84,4%	83,0%	81,5%	80,0%	78,5%	77,1%

LEÑA CON 25% H.b.h. P.C.I.

EFICIENCIA COMBUSTION P.C.I.=	25%	25%	25%	Leña Kcal/kgr.	25%	3080	25%	Carlos W. Thomasset 1991	25%	25%
Humedad	140 ºC	160 ºC	180 ºC	200 ºC	220 ºC	240 ºC	260 ºC	280 ºC	300 ºC	320 ºC
CO2=19%	92,6%	91,5%	90,4%	89,3%	88,1%	87,0%	85,9%	84,8%	83,6%	82,5%
CO2=18%	92,3%	91,1%	90,0%	88,8%	87,7%	86,5%	85,3%	84,2%	83,0%	81,8%
CO2=17%	91,9%	90,8%	89,6%	88,4%	87,2%	86,0%	84,7%	83,5%	82,3%	81,0%
CO2=16%	91,6%	90,3%	89,1%	87,8%	86,6%	85,3%	84,0%	82,8%	81,5%	80,2%
CO2=15%	91,2%	89,9%	88,6%	87,2%	85,9%	84,6%	83,3%	81,9%	80,6%	79,2%
CO2=14%	90,7%	89,3%	87,9%	86,6%	85,2%	83,8%	82,4%	81,0%	79,5%	78,1%
CO2=13%	90,1%	88,7%	87,2%	85,8%	84,3%	82,8%	81,3%	79,8%	78,3%	76,8%
CO2=12%	89,5%	88,0%	86,4%	84,9%	83,3%	81,7%	80,1%	78,6%	77,0%	75,4%
CO2=11%	88,7%	87,1%	85,4%	83,8%	82,1%	80,4%	78,7%	77,0%	75,3%	73,6%
CO2=10%	87,8%	86,0%	84,3%	82,5%	80,7%	78,8%	77,0%	75,2%	73,3%	71,5%
CO2=9%	86,7%	84,8%	82,8%	80,9%	78,9%	76,9%	74,9%	72,9%	70,9%	68,9%
CO2=8%	85,3%	83,2%	81,0%	78,9%	76,7%	74,5%	72,3%	70,1%	67,9%	65,7%

Pequeño Manual del Foguista 10a. ed. año 2011

F.Oil CALEFACCION P.C.I. F.Oil PESADO CRACKING P.C.I.

EFICIENCIA COMBUSTION =	P.C.I.	P.C.I.	P.C.I.	F.Oil Ca	P.C.I.	P.C.I.	Carlos W. Thomasset 1990	P.C.I.	P.C.I.	P.C.I.
P.C.I.	140 ºC	160 ºC	180 ºC	200 ºC	220 ºC	240 ºC	260 ºC	280 ºC	300 ºC	320 ºC
CO2=15%	94,7%	93,9%	93,1%	92,3%	91,5%	90,7%	89,9%	89,1%	88,3%	87,5%
CO2=14%	94,3%	93,5%	92,7%	91,8%	91,0%	90,2%	89,3%	88,5%	87,6%	86,7%
CO2=13%	94,0%	93,1%	92,2%	91,3%	90,4%	89,5%	88,6%	87,7%	86,8%	85,9%
CO2=12%	93,5%	92,6%	91,6%	90,7%	89,7%	88,8%	87,8%	86,8%	85,9%	84,9%
CO2=11%	93,0%	92,0%	91,0%	90,0%	88,9%	87,9%	86,8%	85,8%	84,7%	83,7%
CO2=10%	92,4%	91,3%	90,2%	89,1%	88,0%	86,8%	85,7%	84,6%	83,4%	82,3%
CO2=9%	91,7%	90,4%	89,2%	88,0%	86,8%	85,5%	84,3%	83,0%	81,8%	80,5%
CO2=8%	90,7%	89,4%	88,0%	86,7%	85,3%	83,9%	82,5%	81,2%	79,8%	78,4%
CO2=7%	89,5%	88,0%	86,5%	84,9%	83,4%	81,8%	80,3%	78,7%	77,1%	75,6%
CO2=6%	87,9%	86,2%	84,4%	82,6%	80,9%	79,1%	77,3%	75,5%	73,7%	71,8%
CO2=5%	85,7%	83,6%	81,5%	79,4%	77,3%	75,2%	73,1%	70,9%	68,8%	66,6%
CO2=4%	82,3%	79,7%	77,2%	74,6%	72,0%	69,4%	66,7%	64,1%	61,5%	58,8%

EFICIENCIA COMBUSTION =	P.C.I.	P.C.I.	P.C.I.	F.Oil Pe	P.C.I.	P.C.I.	Carlos W. Thomasset 1994	P.C.I.	P.C.I.	P.C.I.
P.C.I.	140 ºC	160 ºC	180 ºC	200 ºC	220 ºC	240 ºC	260 ºC	280 ºC	300 ºC	320 ºC
CO2=16%	94,6%	93,8%	93,0%	92,2%	91,4%	90,6%	89,8%	89,0%	88,2%	87,4%
CO2=15%	94,3%	93,5%	92,6%	91,8%	91,0%	90,1%	89,3%	88,4%	87,5%	86,7%
CO2=14%	94,0%	93,1%	92,2%	91,3%	90,4%	89,5%	88,6%	87,7%	86,8%	85,9%
CO2=13%	93,6%	92,6%	91,7%	90,7%	89,8%	88,8%	87,9%	86,9%	85,9%	84,9%
CO2=12%	93,1%	92,1%	91,1%	90,1%	89,0%	88,0%	87,0%	86,0%	84,9%	83,9%
CO2=11%	92,5%	91,5%	90,4%	89,3%	88,2%	87,1%	86,0%	84,8%	83,7%	82,6%
CO2=10%	91,9%	90,7%	89,5%	88,3%	87,1%	85,9%	84,7%	83,5%	82,3%	81,0%
CO2=9%	91,1%	89,8%	88,5%	87,2%	85,8%	84,5%	83,2%	81,9%	80,5%	79,2%
CO2=8%	90,1%	88,6%	87,2%	85,7%	84,2%	82,8%	81,3%	79,8%	78,3%	76,8%
CO2=7%	88,8%	87,1%	85,5%	83,8%	82,2%	80,5%	78,9%	77,2%	75,5%	73,8%
CO2=6%	87,0%	85,1%	83,2%	81,3%	79,4%	77,5%	75,6%	73,7%	71,7%	69,8%
CO2=5%	84,6%	82,4%	80,1%	77,9%	75,6%	73,3%	71,0%	68,7%	66,4%	64,1%

HEAVY FUEL OIL - FIREWOOD - Heating Fuel Oil - NATURAL GAS

F.OIL PESADO

P .Calorífico / Temperatura	CORTAR, VENTANILLA REGLA	Exc.Aire	Exc. 02
CO2=16%		4%	0,9%
CO2=15%		11%	2,1%
CO2=14%		18%	3,4%
CO2=13%		27%	4,6%
CO2=12%		37%	5,9%
CO2=11%		49%	7,2%
CO2=10%		63%	8,4%
CO2=9%		81%	9,7%
CO2=8%		103%	10,9%
CO2=7%		131%	12,2%
CO2=6%		169%	13,5%
CO2=5%		222%	14,7%

LEÑA

Humedad / Temperatura	CORTAR, VENTANILLA REGLA	Exc.Aire	Exc. 02
CO2=19%		2%	0,4%
CO2=18%		8%	1,5%
CO2=17%		14%	2,6%
CO2=16%		21%	3,7%
CO2=15%		29%	4,8%
CO2=14%		38%	5,8%
CO2=13%		48%	6,9%
CO2=12%		60%	8,0%
CO2=11%		75%	9,1%
CO2=10%		92%	10,2%
CO2=9%		113%	11,3%
CO2=8%		140%	12,3%

F.OIL CALEFACCION

P .Calorífico / Temperatura	CORTAR, VENTANILLA REGLA	Exc.Aire	Exc. 02
CO2=15%		5%	1,0%
CO2=14%		12%	2,4%
CO2=13%		20%	3,7%
CO2=12%		30%	5,0%
CO2=11%		41%	6,4%
CO2=10%		54%	7,7%
CO2=9%		71%	9,0%
CO2=8%		91%	10,4%
CO2=7%		118%	11,7%
CO2=6%		153%	13,0%
CO2=5%		202%	14,3%
CO2=4%		276%	15,7%

GAS NATURAL

P .Calorífico / Temperatura	CORTAR, VENTANILLA REGLA	Exc.Aire	Exc. 02
CO2 =11,5%		4%	0,9%
CO2 =11,0%		8%	1,8%
CO2 =10,5%		13%	2,7%
CO2 =10,0%		18%	3,5%
CO2 =9,5%		24%	4,4%
CO2 =9,0%		30%	5,3%
CO2 =8,5%		37%	6,1%
CO2 =8,0%		45%	7,0%
CO2 =7,5%		54%	7,9%
CO2 =7,0%		64%	8,8%
CO2 =6,5%		76%	9,6%
CO2 =6,0%		90%	10,3%

Once the COMBUSTION EFFICIENCY and TRANSFER have been read, they can be compared to the efficiency of a more efficient boiler or to the improved flue values of the same boiler (reducing excess air or flue temperature, after soot or scale removal, or repairs to the internal gas distribution, etc., which improves heat transfer).

Using the following table (next page), enter the readings obtained in the left-hand column and then, finding the desired value in the top horizontal column, locate the corresponding savings at the intersection of both.

These savings allow us to compare boilers or the same boiler under optimal conditions.

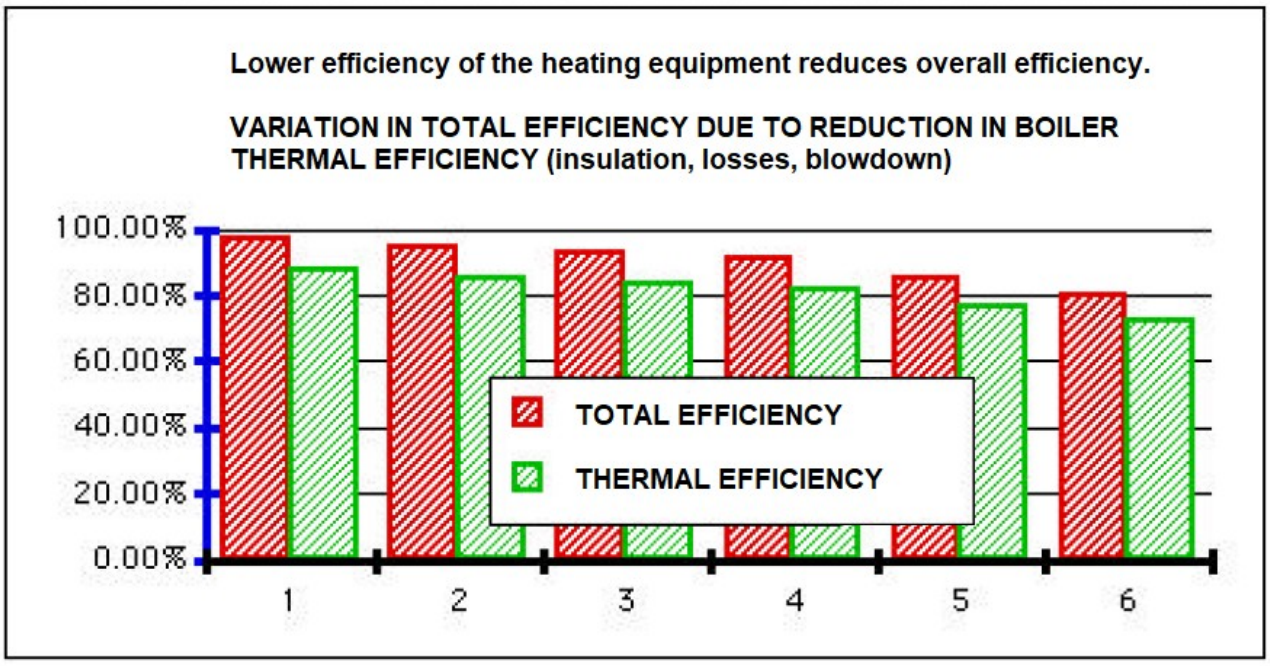
POTENTIAL SAVINGS BY IMPROVING COMBUSTION AND TRANSFER CONDITIONS:

Efficiency to be improved (left vertical column)
Improved efficiencies (horizontal row)
>> Resulting % Fuel Savings

Pequeño Manual del Foguista 10a. ed. *año 2011*

POSIBLE AHORRO AL MEJORAR CONDICIONES DE COMBUSTION Y TRANSFERENCIA

	Eficiencias mejoradas:						
Eficiencias	80%	82%	84%	86%	88%	90%	92%
a mejorar:	**Ahorro de combustible**						
60%	25,0%	26,8%	28,6%	30,2%	31,8%	33,3%	34,8%
62%	22,5%	24,4%	26,2%	27,9%	29,5%	31,1%	32,6%
64%	20,0%	22,0%	23,8%	25,6%	27,3%	28,9%	30,4%
66%	17,5%	19,5%	21,4%	23,3%	25,0%	26,7%	28,3%
68%	15,0%	17,1%	19,0%	20,9%	22,7%	24,4%	26,1%
70%	12,5%	14,6%	16,7%	18,6%	20,5%	22,2%	23,9%
72%	10,0%	12,2%	14,3%	16,3%	18,2%	20,0%	21,7%
74%	7,5%	9,8%	11,9%	14,0%	15,9%	17,8%	19,6%
76%	5,0%	7,3%	9,5%	11,6%	13,6%	15,6%	17,4%
78%	2,5%	4,9%	7,1%	9,3%	11,4%	13,3%	15,2%
80%	0,0%	2,4%	4,8%	7,0%	9,1%	11,1%	13,0%



Stoker Boiler Handbook 2011, C.W.T. – CHAPTER 9: Efficiency in Boilers

Photograph with our beloved father Carlos Walter Thomasset
A man who did everything in life thinking of others
—family, friends, acquaintances, Uruguay society
—and not for his own.